Intelligent Voice Prosthesis: converting icons into natural language sentences

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Résumé : La *Prothèse Vocale Intelligente* est un système de communication qui reconstitue le sens — supposé — d'une séquence peu structurée d'icônes ou de symboles, et l'exprime par des phrases en langue naturelle (français). Elle a été développée pour l'usage de personnes ne possédant pas la maîtrise du langage oral, et en particulier incapables de s'exprimer en suivant les règles d'une grammaire complexe comme celle de la langue. Nous décrivons ici la construction d'un dictionnaire sémantique de symboles simple et pertinent à partir des corpus de communication icônique relevés auprès d'enfants Infirmes Moteurs Cérébraux (IMC). Nous expliquerons ensuite le mécanisme d'analyse sémantique ascendante qui permet, en déterminant les dépendances entre symboles, de trouver le sens des messages de l'utilisateur. À partir du résultat de cette analyse, un module de transfert lexical choisit les mots français les mieux adaptés pour l'exprimer, et construit un réseau sémantique linguistique. Celui-ci est ensuite hiérarchisé, grâce à une Grammaire d'Arbres Adjoints (TAG) lexicalisée, en arbres syntaxiques de phrases françaises. Enfin, nous décrirons l'interface d'accès paramétrable qui a été définie pour ce système.

Mots-clés : Sémiotique, Analyse de Dépendances, Génération de Langue Naturelle, Handicap de Parole, Communication Augmentée.

Abstract: Intelligent Voice Prosthesis[1] *is a communication tool which reconstructs the meaning of an ill-structured sequence of icons or symbols, and expresses this meaning into sentences of a Natural Language (French). It has been developed for the use of people who cannot express themselves orally in natural language, and further, who are not able to comply to grammatical rules such as those of natural language. We describe how available corpora of iconic communication by children with Cerebral Palsy has led us to implement a simple and relevant semantic description of the symbol lexicon. We then show how a unification-based, bottom-up semantic analysis allows the system to uncover the meaning of the user's utterances by computing proper dependencies between the symbols. The result of the analysis is then passed to a lexicalization module which chooses the right words of natural language to use, and builds a linguistic semantic network. This semantic network is then generated into French sentences via hierarchization into trees, using a lexicalized Tree Adjoining Grammar. Finally we describe the modular, customizable interface which has been developed for this system.*

Keywords: *Semiotics, Dependency Analysis, Natural Language Generation, Speech Impairment, Adaptative and Augmentative Communication.*

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1 Introduction

users' needs

Some people are unable to speak not only because of phonatory or articulatory reasons, but because a neurological handicap deprives them, temporarily or permanently, of their language ability. They suffer from various types of language difficulties, which can consist of missing words, loss of the semantic link between a word and its meaning, inability to structure their speech, etc.

For all these people, no voice synthesis with an interface based on letter or word selection would make up for the speech impairment. They are unable not only to speak, but also, for various reasons, to compose a written sentence.

The users for whom the PVI system is originally designed are people with Cerebral Palsy, in the Kerpape rehabilitation center [6]. These patients suffered from a prenatal or perinatal cerebral damage. They are to various degrees subject to different impairments, affecting neuromotor, articulatory, auditive, oculomotor and visual, cognitive (including linguistic) functions. Most of them have a limited ability to progress in their mastering of language.

The design of our system's interface, which is designed to be used by people with *both* motoric and mental abilities, was carried out with constant concern with these users' needs. We have developed various access methods for people with specific neuromotor troubles (see 6).

iconic communication

A solution which has already been implemented in a "classical" (non-electronic) way by ergotherapists for these linguistically challenged subjects is communicating through pointing at images. The images used for this purpose, depending on each user's abilities and knowledge, can be abstract ideograms (for example the Bliss alphabet [2]) as well as figurative pictures. Henceforth we will refer to these symbols, regardless of their type, as *icons.*

During supervised communication sessions, a person used to communicating with the speech impaired (parent, orthophonist, ergotherapist ...) goes into a process of intelligently *interpreting* the sequence of icons designated, and then formulating it back in natural language sentences. The aim of our system is to make this process automatic and thus widely available.

The observation of practical communication situations with the patients in Kerpape convinced us that a semantic interpretation approach was necessary for this purpose. A simple icon-to-word translation proved to be unsufficient to model the process: the sequences of icons used are not organized into regular structures, but are generally arranged in an order depending on the message's topicality.

An example of an utterance met in these iconic communication corpora will illustrate this point:

`<past-tense-indicator> boat to_eat`

This was intended to mean "*I had a meal in a boat*" (stressing the boat context).

No parser based on Context Free Grammars (CFG), whatever the number of rules, can account for the different meanings of:

`boat to_eat` ("*I eat in a boat*")

and:

`beefsteak to_eat` (“*I eat a beefsteak*”).

The only way to cope with this type of different dependencies is to model some of the natural expertise which allows the experienced communication partner to assign a correct meaning to such utterances, on the basis of a semantic interpretation.

That is why our system is based on the following processes:

- analysis of the semantic content of the icons used, and attribution of a semantic role to each of them;
- lexical choice: determining the best words to use to convey the semantic content;
- linguistic generation: generation of a natural language utterance from a topicalized representation adapted to linguistic semantics.

2 Extracting the lexicon from corpora

The methodological choices described were supported by the analysis of corpora of iconic communication from children with Cerebral Palsy in the Kerpape Rehabilitation Centre.

These corpora were produced by the disabled people ...

- spontaneously:
  - in a situation when they had to communicate;
  - in a situation of exercise (during ergotherapy training sessions, which means with no communicative urge nor time limitations);
- during supervised communication sessions:
  - in an alternated dialogue situation, when some interlocutor could make answers, guess meanings, complete utterances ...

The first situation will most strongly determine the design of the PVI system, since it represents the most important requirements we are trying to meet.[2] The first corpus has thus been thoroughly analysed, the two others giving complementary information on some elements of the lexicon.

The corpus-based building of the lexicon guarantees the most relevant description of the available lexical field, as it allows the system builder (a) not to forget anything which is in the corpus, and (b) not to put anything superfluous in the lexicon.

The analysis of possible variations on the *paradigmatic* dimension (icons/symbols which can take the same place in a given context) allows the icons to be classified into minimal classes which, following [7], we will call *taxemes*. An icon representing a beefsteak and another representing a pizza will be classified as belonging to the same taxeme as they will both tend to appear systematically with the icon representing ‘*to eat*’ in the same contexts. These taxemes are grouped into semantic domains like “alimentation”, “movement”, “game” ...

[2] As a matter of fact, no computer program could eventually replace the understanding skills of a human being used to communicating with the speech impaired (parent, specialist, etc.). The system is therefore designed, in the first place, to give the user access to an autonomous communication device allowing him/her to talk to any person, even unprepared, in an unspecified context.

The regularities observed in the *syntagmatic* dimension (classes of icons which systematically occur together in the sequences) help us build the casual structure of predicative concepts. For example the icon representing '*to eat*' will in most cases, in the corpus, go together with an icon representing a human being or an animal, and with an icon belonging to the class which we have identified to contain '*beefsteak*', '*pizza*', ... This will be expressed in the icon lexicon by giving the icon '*to eat*' a default casual structure implying a first casual function which we will call **agent**, and a second casual function which we will call **object**.

Each icon has its semantic content determined (a) by the taxeme it belongs to, and (b) by elementary meaning features, the *specific* features, which allow icons of the same taxeme to be distinguished.

After the analysis, the icon lexicon is given its structure:

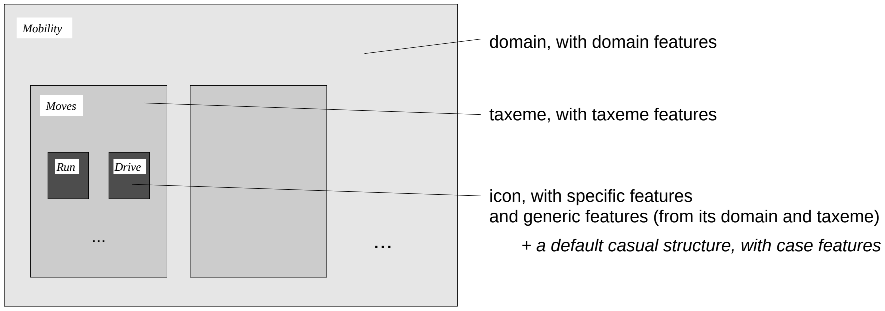

Mobility
Moves
Run
Drive
...
...
domain, with domain features
taxeme, with taxeme features
icon, with specific features
and generic features (from its domain and taxeme)
+ a default casual structure, with case features

Figure 1: The icon lexicon

Without developing the theoretical issues underlying the structure of the lexicon, we will point out that this structure naturally emerges from the corpus analysis. In the framework of lexical semantics [7], the content is precisely based on a description of actual use, which ensures its ability to form the basis of interpretative processes. This approach is openly paraphrastic, and that fits the needs of a semantic analysis system (see 3).

What is the meaning of an icon?

The symbols treated by PVI are represented in a structural semantic system, where the meaning content of every icon lies in fact in the features which distinguish it from the other icons. The elementary features used to describe this meaning are valuated attributes (most of the time binary), which constitute the semantic primitives of the system.

To be able to process meaning, we postulate, although few theoretical studies on this subject support this view, that the visual icons have elementary features which are of the same nature as linguistic semantic features. The difference in our system between icons and words is in the possibly distinct arrangement of these features into clusters which constitute the meaning of icons and words. The issue of specifically visual (or non-linguistic) features and of their role in interpretation is approached in [8] and [3].

3 Semantic analysis

The semantic analysis process tries to reconstruct the meaning of the sequence of icons pointed at by the user. It builds a meaning representation of the user's utterance, in which every icon in the sequence is attributed a semantic role.

The information that we have *a priori* on the meaning of icons is (a) inner features — generic or specific —, (b) a casual structure, if the icon has some *predicative* content, where case features specify the semantic features which the functors are "expected" to possess (see figure 2), based on observations from the corpus.

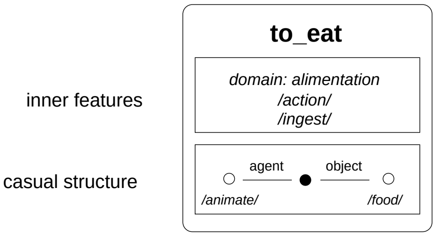


Figure 2: An icon

The creation of a meaning representation then consists in assembling a comprehensive semantic network for the utterance. This is done by assembling the small pieces of semantic network that for every predicative icon, this casual structure constitutes. The basic mechanism of this assembling process is unification of the free slots of a casual structure, conditioned by the compatibility between the semantic features (figure 3).

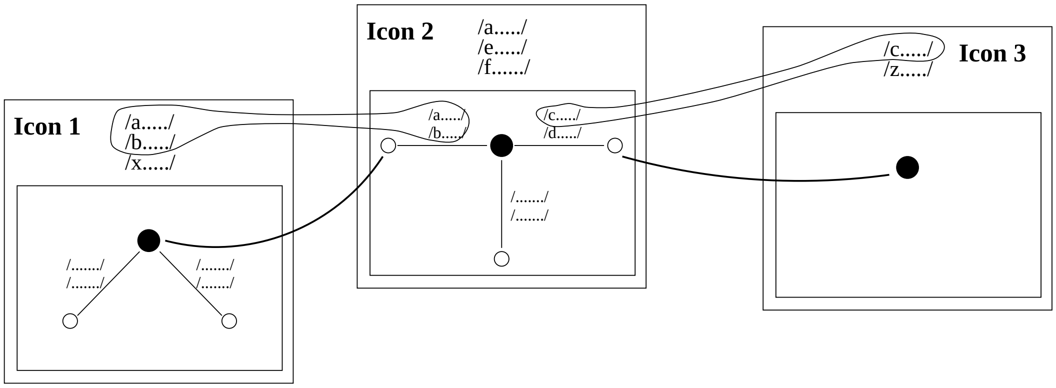


Figure 3: Unifying the free slots of a casual structure

A free node in a partly instantiated network is a slot whose content is an uninstantiated variable. If the specifications attached to the node (the case features) are compatible with a given icon, the variable is instantiated: it takes the icon as its value. If the icon is itself predicative, i.e. it is the head of another partially instantiated network, this second network becomes attached to the first. The process goes on until all possible free slots have been unified.

The search for a solution can be described in the following way:

1 The system scans the input sequence of icons from left to right. When finding a predicative

icon, it looks at its casual structure and picks a free slot;

2 Every icon in the remainder of the sequence is then looked up, aiming to find one which will fill the slot, identifying it as a case filler of the current predicate;

3 When an acceptable solution has been found, another free slot is picked;

4 When an acceptable solution has been found for every slot, the system goes back to scan the input sequence for other predicative icons.

The notion of *compatibility* between semantic features, used to determine whether an icon is an acceptable filler for a given casual slot, can be defined in different ways depending on the selectivity expected from the PVI system. It is a binary relation defined on two sets of semantic features. When applied to (a) the set of "case features" and (b) the semantic features of the candidate, its value characterizes the good candidates.

This binary relation may be:

- mere inclusion, if the semantic constraint expressed by the case features is mandatory:

  $C(a, b)$ is 1 if all features in a are present in b and have the same value, 0 otherwise,

  (this means that a good candidate must have *all* the semantic features expected from the functor);

- a scaled product between the two sets if more or less acceptable solutions may be found, for example:

  $C(a, b)$ is the number of features of a which are present and have the same value in b, divided by the total number of features in a,

  (this means that approximate solutions are allowed).

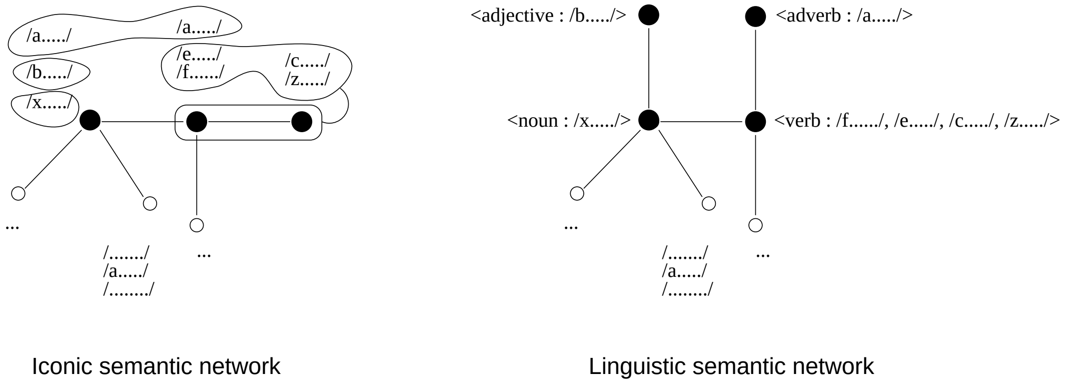
During the analysis process, not only one solution, but many, will be explored. This is done through the implementation in Prolog and its backtrack facility. It is therefore natural that we seek to find the *best* solution between all the possible ones. This is the goal of "scoring" the solutions with scaled semantic compatibility information such as described above. Incomplete and ambiguous information will then be processed in the best possible way. A similar approach has been described in [5].

The result of an analysis is a semantic network expressed in a linear form. The linear order of the network results from the processing order of the different predicates, i.e. from the order in which they appeared in the input sequence. It represents the topical orientation of the message.

4 Lexical choice

Before being formulated into natural language, the semantic content of the user's message, as resulting from the analysis, has to go through a process of lexical choice. This process (figure 4) will build a *linguistic* semantic network fit to be generated into natural language words and sentences.

This lexical choice step is motivated by the observation that there is no simple bijection between icons and words, and that their meaning content is not necessarily isomorphic. The semantic network resulting from the analysis of a message composed with icons is not, strictly speaking, made up of sememes but of what we might call **semioms**: clusters of semantic features which do not necessarily match up linguistic entities.



Iconic semantic network

Linguistic semantic network

Figure 4: The lexical choice process

During the lexical choice phase, clusters of semantic features of a linguistic nature will be chosen to express those semioms in natural language in the best possible way.

A lexical choice component has proved to be a necessary preliminary module to any natural language generation system [9].

The implemented mechanisms for this lexical choice component are:

- **short-circuit:** some semantic refinement expressed explicitly with a casual construction might be implicitly contained in the inner features of a single word:

  A [S$_A$] — B [S$_B$] → L [S$_A \bigcup$ S$_B$]

- **derivation:** some icons with too "rich" a content for natural language might have to be expressed with more than one word:

  I [S$_A \bigcup$ S$_B$] → A [S$_A$] — B [S$_B$].

These mechanisms have already been explored for automatic translation studies, the problem of lexical choice being also an important issue in this field[3].

5 Generation

The last phase is the generation of a natural language sentence conveying the meaning of the linguistic semantic network. This operation is based on the principle that every sememe may be expressed through a small number of lexemes (in many cases one — sometimes two or three, depending on the syntactic function, e.g. 'work' [*noun*] vs. 'to work' [*verb*]), each of which is in its turn lexicalised through a certain number of morphemes (for inflexion).

The semantic structure of casual relations linking a sememe to its casual fillers is itself expressed in natural language through a morpho-syntactic structure which native speakers of a language will identify. Among the mechanisms that natural languages have developed in this purpose, French uses chiefly the following three:

- word order (e.g. <subject> <verb> <object> . . .);

[3] translaters are familiar with this type of content redistribution, every natural language having its unique way of expressing meaning, like the German phrase '*über den Fluß schwimmen*' being expressed rather in French by '*traverser la rivière à la nage*'.

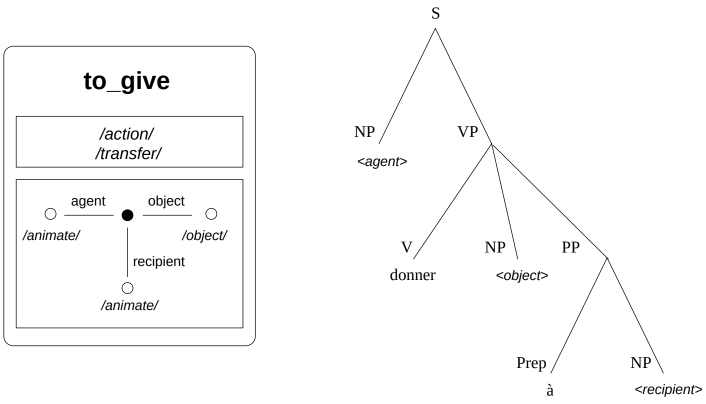
- inflexion (plural of nouns, conjugation of verbs . . .);
- functional morphemes (e.g. “*à*” (*at, to*), “*de*” (*of, from*), “*sur*” (*on*) . . .).

Our lexicon stores, for every entry, elementary syntactic trees representing possible phrase constructions. Each of these elementary syntactic trees specifies the following information:

- the lexeme corresponding to the sememe;
- the morphosyntactic structure expressing its casual structure.

This is a *lexicalized grammar*.

The elementary trees contain the information necessary to specify the three mechanisms listed above. The word order is reflected in the tree structure; the functional morphemes, if any, are terminal nodes of the elementary tree; the flexion is given by constraints propagated from upper to lower nodes in the tree (unification features). The example in figure 5 illustrates this.



French turn of phrase “donner à”, like in: “ *Jean donne une bouteille à Pierre* ”

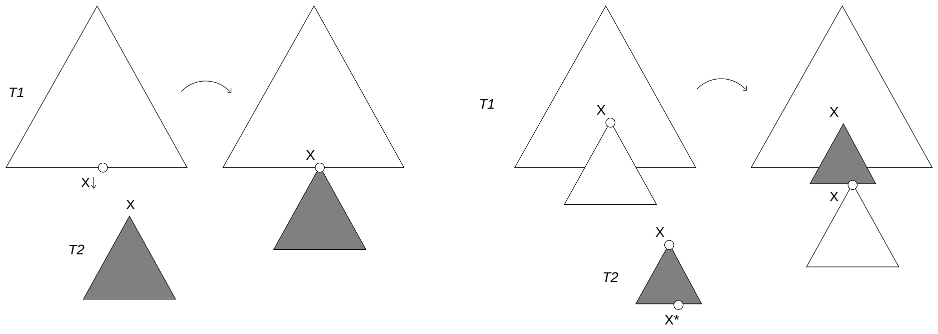
Figure 5: A semantic casual structure and a possible morphosyntactic expression

In our system, the generation of the sentence corresponding to the semantic network is done during a scan over the network, considering predicates in turn in the topical order, following the semantic links. It corresponds to a one shot run over a spanning tree of the network.

For every node (sememe) met in the network, a corresponding elementary tree is selected. Elementary trees are assembled using the following operations:

- **substitution**, for the “compulsory” functors
  (a branch is ready for them in the tree; e.g. *agent*, *object* and *recipient* in the tree figure 5);
- **adjunction**, for the “optional” functors
  (like, for example, if we had a locative complement in the example above),

  or for a new predicative sememe for which an already generated sememe acts as functor (like, for example, a qualifying adjective).



a. Substitution of tree T2 in tree T1

b. Adjunction of tree T2 into tree T1

Figure 6: The operations on trees in TAGs

These two operations on trees, substitution and adjunction (see figure 6), define a Tree Adjoining Grammar (TAG). Such grammars have been introduced by [4], and a French adaptation has been proposed by [1].

When the system comes to a new predicative icon which cannot be generated through an adjunction to the sentence tree currently being built, a new sentence tree is generated. A network can thus be generated into more than one tree.

The output sentences are the list of inflected morphological forms of the terminal nodes of those trees. These morphological forms are found in a morphological lexicon.

The sentences are eventually vocalized by a text-to-speech voice synthesis device.

6 Interface

Some potential users of the PVI system have neuromotor troubles which make the use of classical, widespread interfaces difficult for them. One of the goals of the system is to provide them with an adapted interface.

A Human-Computer Interface (HCI) consists of a set of material devices and logical routines allowing the person and the computer to exchange information. The PVI system is to be installed and run on a Macintosh™ type computer, which offers in its standard operating system a graphical window manager interface and supports many input/output devices. Some disabled people may not use very well the most common input devices: keyboard, mouse, trackball or joystick. Some more specific devices, such as a tongue contactor or ultrasonic “headphones” (a head-commanded pointing device) may be used in some cases. The simplest device might consist of a mere push button.

These users are compelled to use simplified hardware devices. The information supplied to the machine is all the poorer. The support of these devices thus demands from the interface software specific methods to assist the user in his/her interaction with the machine.

Architecture

In the case we are interested in, we expect the interface to allow the user to point at a sequence of symbols, and to be able to synthetize an oral French sentence. Given the variability of possible neuromotor impairments challenging some users of PVI, and the diversity of devices able to be used, it is vital to design an open and flexible system. The interface for PVI is in nearly every detail customizable.

The graphical interface is a segmented window displaying icons. It deals with four data types: text, pictures, sounds and moving pictures. The internal representation of an icon contains data of one or more of these types, which means that an icon can be as much a sound icon as a visual icon. For example, the 'cat' icon displays the drawing of a cat, the string "*chat*", and a meowing sound.

Apart from their perceptive content, the icons may be of two types: symbols or actions. The symbols are transmitted to the semantic analyser, whereas the actions directly command the parameters of the interface (change window, louder sound, etc.).

The windows are used to group homogeneous icons. All the static aspects (position, size, color of icons and windows, sound volume, etc.) and all the dynamic aspects (pointing method used, editing commands, etc.) of the interface are customizable.

Dynamics

What are the methods that may be used to point at the icons composing the message?

In a first case, the user has sufficient motor abilities to use a pointing device commanding a graphic cursor (like a mouse). (S)he may then click on the selected icon, or else leave the cursor unmoved for a minimum time to activate an implicit selection.

In a second case, the user is able to use a keyboard and (s)he may access a large number of keys. Every key will then correspond to an icon on the screen, possibly on a special keypad. This is direct access designation.

In the last case, the user's mobility is reduced and (s)he can only use a binary information device (like a push button). The system has to make up for the missing information by a motion automaton: since the user cannot move the cursor, the cursor moves from one square to another in the window, and the user just has to validate the selected icon when the cursor is in front of it.

There are more or less sophisticated motion automata:

- the cursor is displayed on every square in the window in turn;
- the cursor is a window-wide line and is displayed on each line in turn in the window. The user stops it when it is positioned on the line where the selected icon is. Then a cursor moves from one square to another along the line.
- the cursor is a surface which can encircle a region of the screen. The window is divided into groups of squares. The cursor is displayed in turn on each of these groups of squares. When the user has selected one group, the cursor may continue to move, within it, on subgroups of squares, or on the squares themselves.

For example, if the window is composed of 32 squares arranged on 4 lines and 8 columns, designating an icon might take from 1 to 32 moves with the first method, from 2 (1+1) to 12 (4+8) moves with the second one, and — assuming that the selected group of squares is divided in two at each step —, will always take 5 moves with the third method.

7 Conclusion

The PVI system is a fully-implemented system, although as yet limited to a small semantic domain. It carries out the entire processing chain for converting messages from one sign system to another. For the needs of our application, we were led to develop a semantic interpretation mechanism to understand the icon sequences. We also have developed a generation module which implements the operations on trees in Tree Adjoining Grammars; these operations constitute a good model to express semantic unification in natural language.

PVI has been designed to have a reasonable robustness inside its domain. For field test, the system has entered a preliminary validation phase in the Kerpape Rehabilitation Centre. It has received encouraging comments regarding its modularity and flexibility, which are important features for disabled users.

Future work will be dedicated to a subtler analysis of the relation between the semantic contents of two different sign systems. Context analysis should also lead to a better processing of ambiguities and reference.

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